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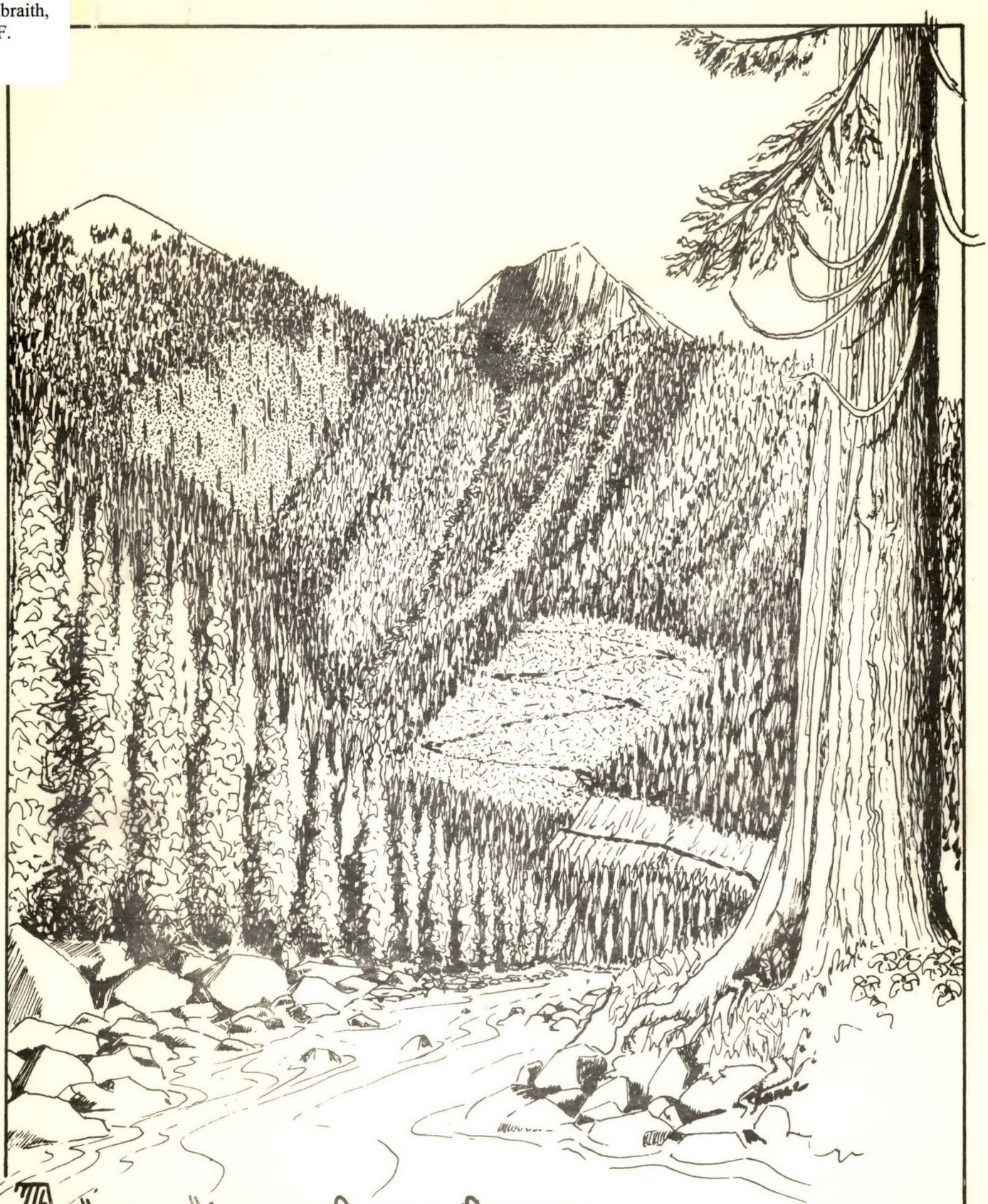

# A WATER YIELD and CHANNEL STABILITY ANALYSIS PROCEDURE

Kootenai National Forest

# A WATER YIELD AND CHANNEL STABILITY ANALYSIS PROCEDURE

By

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# PREFACE

The Organic Act (1897)

" . . . No national forest shall be established, except to improve or protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flow, and to furnish a continuous supply of timber . . ."

Weeks Law (1911)

" . . . The Secretary of Agriculture is authorized and directed to examine, locate, and recommend for purchase such forested, cut over, or denuded lands within the watersheds of navigable streams as in his judgment may be necessary to the regulation of the flow of navigable streams or for the production of timber . . ."

Framework for the Future (1971)

Policy: "Help ensure water yields of the quality and quantity needed."
Region 1 Management Direction: "Promote measures to maintain or improve existing water quality and quantity through an inventory and surveillance of National Forest water resources."

Objective: "Protect and improve the quality of air, water, soil, and natural beauty."

Region 1 Management Direction: "In case of conflict between quantity and quality, resolve in favor of quality."

Purpose

The Multiple Use Plan of the Kootenai National Forest has the following coordinating requirement (II, 2):

"Vegetation manipulation will be planned to limit the increase in the average annual discharge to 8% and the increase in the annual peak discharge to 15% for 3rd order or larger watersheds. These limits can be exceeded if a channel stability and cutting pattern examination determines that there will not be an increase in sediment production or a decrease in fisheries habitat quality."

This coordinating requirement has a purpose; namely to ensure that the hydrologic stability or equilibrium of each national forest watershed will be maintained. It has been found by studies of watershed and channel conditions throughout Region 1 that damage can take place following fire, clearcut logging, or a combination of both when the annual runoff has exceeded 8-10% of the "normal" (1). Normal runoff is that amount which occurs under complete forest cover for the watershed. The implication of the 8-10% figure is this-- the potential for watershed damage increases above this level. Some watersheds on the Kootenai National Forest, as evidenced by past fire and/or timber harvesting, have sustained flows in the 15-20% increase range without exhibiting signs of hydrologic imbalance. Other watersheds have had serious erosion and channel problems with increases in the 5-10% range. By and large, however, the 8% limit provides a reasonable safe level for the watersheds of the Kootenai National Forest.

A glance at an aerial photograph taken nearly anywhere on the Kootenai National Forest will demonstrate the fact that in the near future there will be very few watersheds which have not been entered for timber harvests. Many of these watersheds have second or third generation timber sales at present, and this pattern will increase. The water yield analysis procedure will help in the medium and long range planning of timber management in these watersheds.

The procedure given in this report makes it possible to calculate the maximum probable increase in surface runoff which can reasonably be ex-

pected following modifications of the vegetation, mainly the forest canopy. As will be seen, the procedure makes use of the latest hydrologic information pertaining to the Kootenai National Forest and the most recent watershed research studies which apply to this area. The procedure is specific to the Kootenai National Forest, also, in that land types and habitat types inventoried in the Multiple Use Planning effort are used directly in the calculations. This procedure also follows the same general approach of procedures used on the other National Forests (2), (3), (4), (5).

## Forest Hydrology Background

The water yield analysis procedure for the Kootenai National Forest is based upon a few fundamentals of forest hydrology. In the first place it is well established by common sense as well as experimental observation that the amount of river flow from any watershed is controlled by the amount of precipitation which takes place on the watershed (6). This fact enables one to develop a precipitation-surface runoff relationship for any area which has measurements of precipitation and stream discharge. In Montana, just such a precipitation-surface runoff relationship has been constructed by the Soil Conservation Service, shown in Figure 2 (7). This study has provided the most accurate precipitation map and subsequent runoff estimation currently available. The results from Figure 2 are sufficiently accurate for use in the water yield analysis procedure.

Since the time of the first experimental watershed study at Wagonwheel Gap, Colorado, 1911, all the succeeding watershed studies have come to the same conclusion--removing trees from a watershed increases the amount of water flowing from that watershed for a period of time (8). This increase in flow has been explained in many ways (9) (10), but boils down to two main sources--transpiration reduction and interception-redistribution gain. The elimination of interception of snow and rain by tree foliage was once considered to be a major component of surface runoff increase following timber harvesting. Research studies of interception and redistribution processes are coming to the opposite conclusion (11) (12); such that the total contribution to increased flow is unlikely to be greater than 20% for interception-redistribution. By process of elimination, transpiration reduction accounts for 80% or more of the

increase in streamflow following timber harvesting or fire. In a heavy snowpack region such as the Kootenai National Forest, the increase in surface runoff comes mainly during the spring snowmelt period with a smaller amount extending into the summer.

The magnitude of increases to stream flow has shown a predictable amount of variation (8) (13), depending upon the amount of rainfall, evaporation potentials, types of silvicultural harvest methods, and amount of trees removed from the area. At two experimental watersheds which can be related to the Kootenai National Forest annual increases following clearcutting were approximately 13 inches (Priest River Experimental Forest (14) and 18-21 inches (H. J. Andrew Experimental Forest (15)). The Priest River study measured only the changes in the snowpack, not in the stream flows, while the H. J. Andrews study measured the total increase in stream flow. Since the forests and general climate of the Kootenai National Forest are not as optimum for transpiration efficiency as at the H. J. Andrews area (west slope of the Oregon Cascades), the maximum increase for the Kootenai National Forest is probably somewhat less than 18-21 inches annually. For the water yield analysis procedure a maximum of 16 inches (1.3 acre-feet) was selected for the Kootenai National Forest. This is a unit area increase, or in other words, 16 inches per acre per year. This maximum figure does not apply uniformly across the Kootenai National Forest for the following reasons:

1. Marginal sites have fewer trees per acre to transpire so the increase in stream flow will be less than from better growing sites.
2. Some sites have shallow soils which cannot retain as much water as deeper soils so the increases to stream flow will be less from the shallow soils.
3. At the higher elevations in the subalpine the maximum evaporating power of the atmosphere can fall below 16 inches annually.

Potential evaporation and soil depth are the primary factors limiting streamflow increases following timber harvesting or fire from an area with a closed forest canopy. The change in potential evaporation with elevation is shown in Figure 1 for the Kootenai National Forest. This

Figure 1 . . The potential evaporation was calculated from the Thornthwaite water balance procedure which uses mean monthly temperatures as the basis of the calculation.

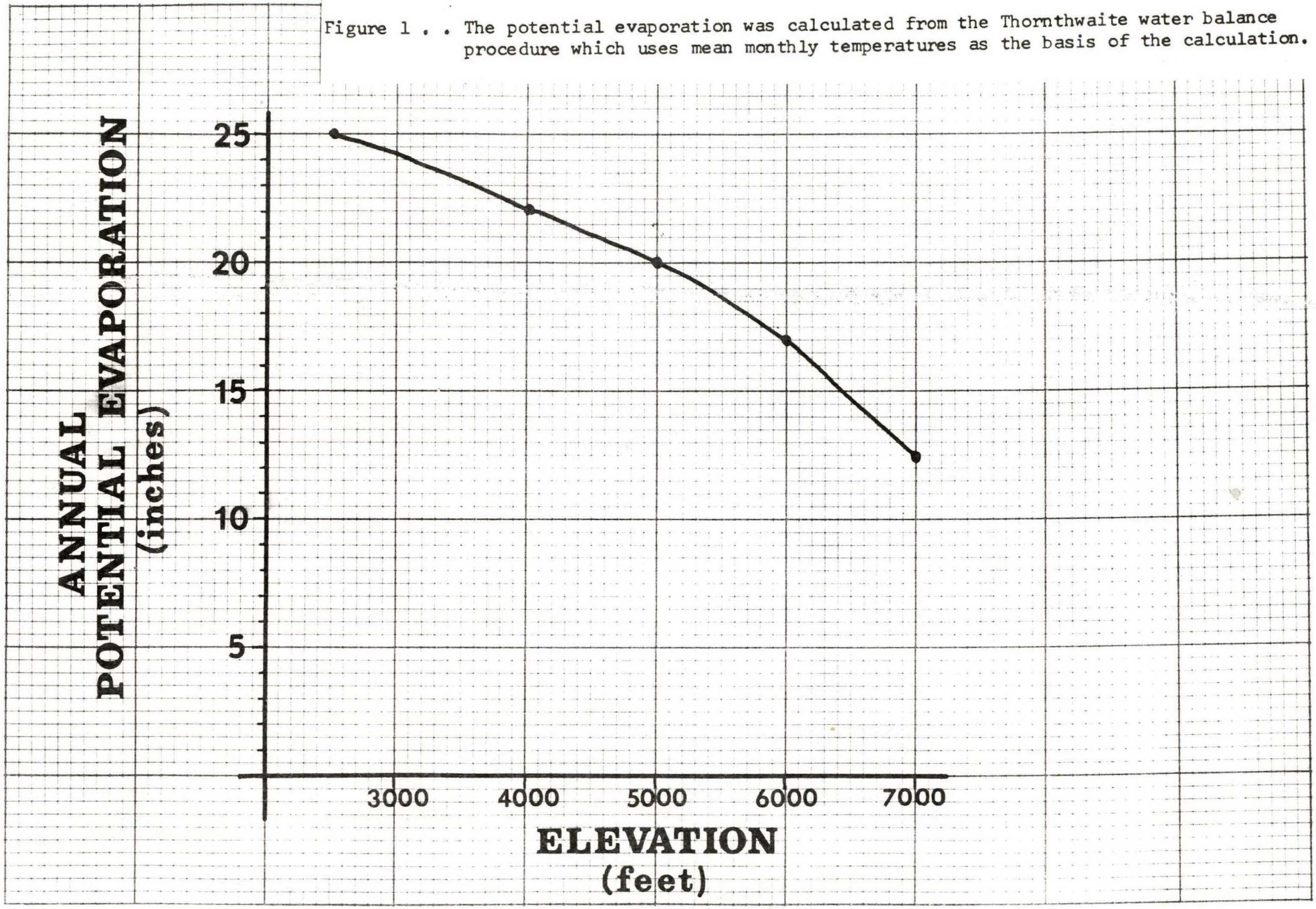


figure shows an upper limit of 25 inches at 2500 feet decreasing to 12 inches at 7000 feet. This range of 25-12 inches is the maximum amount of transpiration which can occur. Actual increases in streamflow due to transpiration reduction will be less than the 25-12 inch range since the soil water in the surface 1 to 1.5 feet of soil will be evaporated both before and after tree removal. Using a water retention capacity of 25% for the predominately sandy loam, glacial till soils of the Kootenai National Forest, the surface layer of the soils lose about 4 inches of water on the average annually by evaporation regardless of whether trees are removed or not. When this 4 inches is subtracted, the maximum increase in stream flow due to transpiration reduction becomes 21 inches at 2500' elevation and 8 inches at 7000'.

Within this elevational range soil depths can further limit the stream flow increases due to transpiration reduction. A typical Kootenai N.F. soil retains 3 inches of water per foot of soil. Approximately 4 inches is evaporated from the surface layer of the soil with or without vegetative cover. Since typical Kootenai N.F. soils range from two to six feet in depth, a maximum difference of 12 inches of water is available for transpiration. This is also, therefore, the maximum change in stream flow due to variable soil depths following transpiration reduction.

These conclusions dealing with the variation in stream flow increases following tree removal are summarized in Figure 3. This graph shows increases in surface runoff by elevation and land type. The three land type groups vary according to the average depth of soil to bedrock or an impervious layer. Group 1 has soils averaging 2 feet in depth or less; Group 2 - 4 feet in depth; and Group 3 - 6 feet or greater in depth. At the 2500' to 4000' elevation the effect of discontinuous natural forest cover on the more severe south aspects is taken into account by those portions of the graph marked "S". The same effect, though less pronounced, is given for other aspects at the same elevations. At the higher elevations the effect of a reduction in evaporation due to lower temperatures can be seen in curve 3, where from 5000' to 6500' elevation the decrease in the amount of water yield increase is following the maximum for potential evaporation, discussed earlier. The potential evaporation does not influence the Group 2 land types until 6300' elevation and does not affect the Group 1 land types at all.

The number of trees removed in a timber sale and the pattern in which the trees are removed will have a great influence upon the increase in stream flow which occurs. Under silvicultural methods employed in even-age management, there is evidence that the amount of stream flow increase is roughly proportional to the percentage of the stand removed (8) (13) (15). For selection methods of timber harvesting, the increases in stream flow are less than for even-age methods and the recovery can be complete in less than 10 years (17). These results are illustrated in Figure 4 which shows the percent of stand removed, as related to equivalent clearcut area for even-aged management and direct acre-feet/acre for selection and commercial thinning. The percentage of stand removed and basal area reduction are indices to the actual change in occupancy of the site. The total amount of transpiring surface (foliage) removed and root volume decrease are the important factors in terms of transpiration reduction leading to stream flow increase.

The next question which relates to the water yield analysis procedure is; for how long and at what rate do the increases in stream flow persist. In only one or two experimental watershed studies has a long enough period of time elapsed for complete hydrologic recovery to take place (8). Streamflow increase is believed to take 15 - 30 years to subside on the west slope of the Oregon Cascades (15). At the Fool Creek experimental watershed in Colorado, however, with a snowfall pattern similar to northwestern Montana, 15 years have elapsed with little observable change in the streamflow increase (21). Since the vegetative recovery portion of the water yield analysis procedure will be applied to individual cutting unit areas rather than whole watersheds, it was decided to base hydrologic recovery on the forest habitat type system currently in use on the Kootenai National Forest. Because growth rates are closely correlated to forest habitat types, it is logical to base hydrologic recovery upon forest habitat types (22).

In Figure 5 nine curves are shown for the forest habitat types found on the Kootenai National Forest. The curves are drawn on a semi-log scale since it has been demonstrated that vegetative-hydrologic recovery is of an exponential character (15). Transpiration recovery is complete in 30, 45, and 60 years for curves 1, 3, and 6 respectively. The additional period of time for each curve represents interception-redistribution recovery which takes

Figure 2 . . Taken from the Soil Conservation Service Report, Hydrology of Mountain Watersheds, 1971.

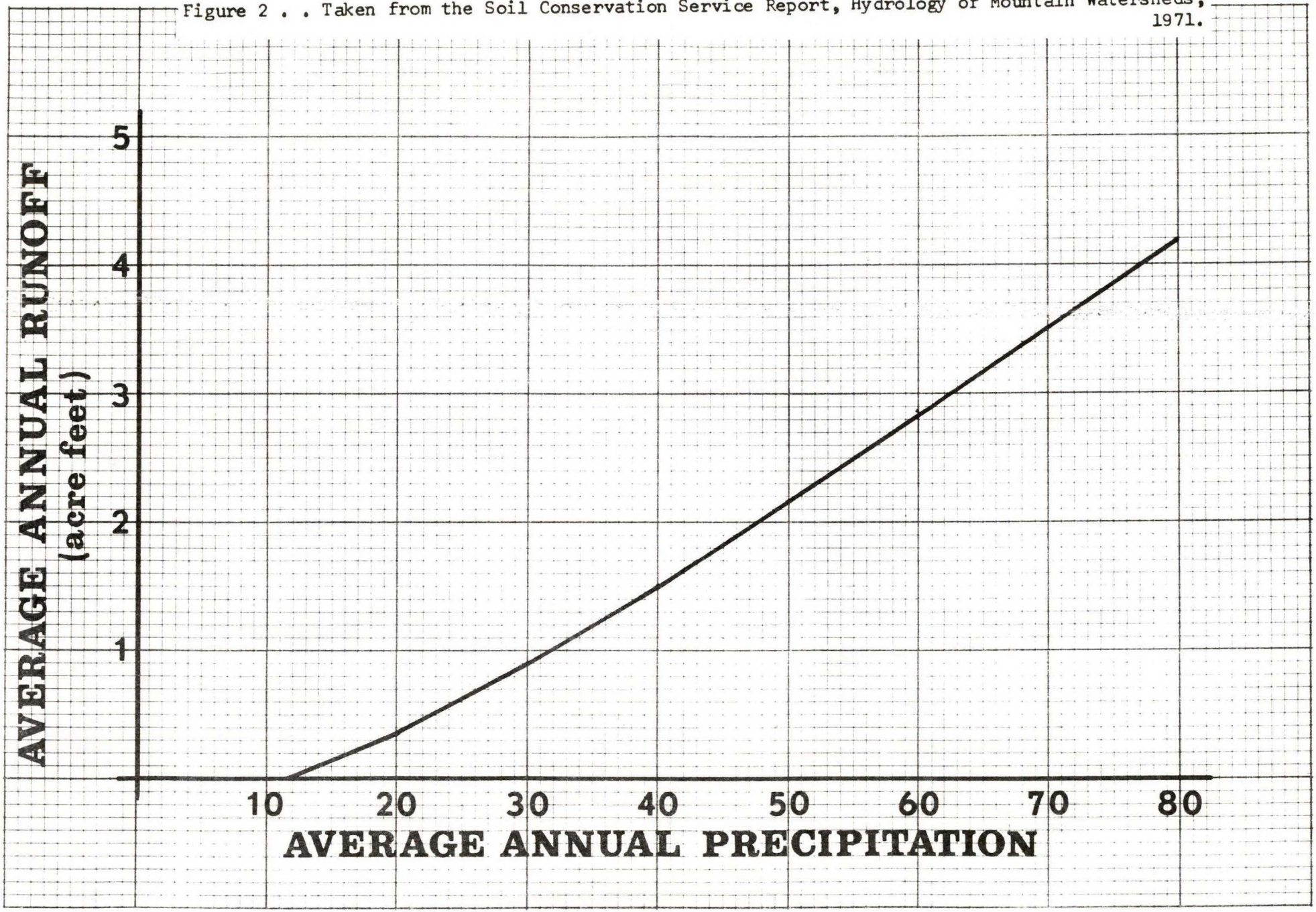


Figure 3 . . Water yield increase is shown for land types by elevation.

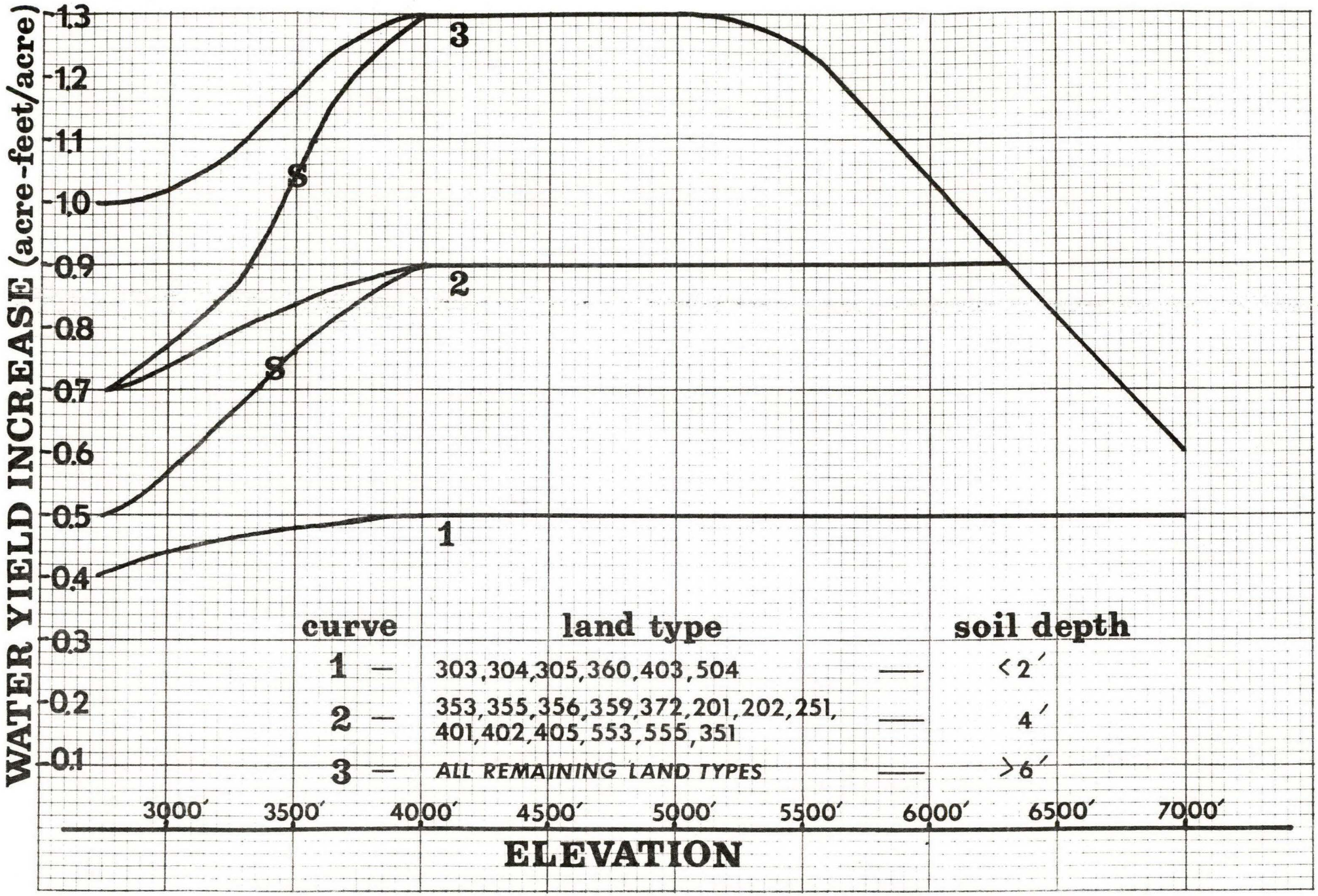
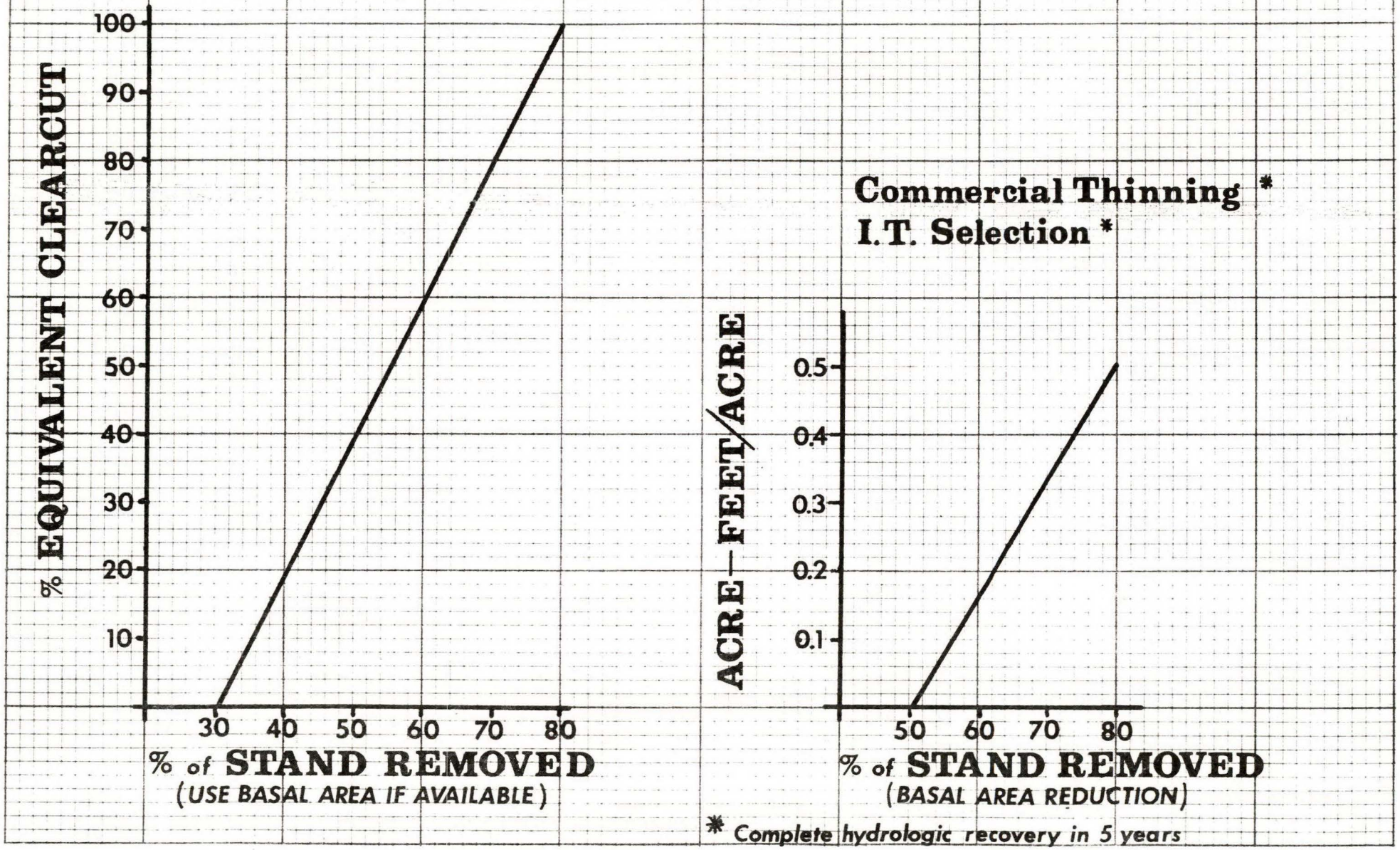
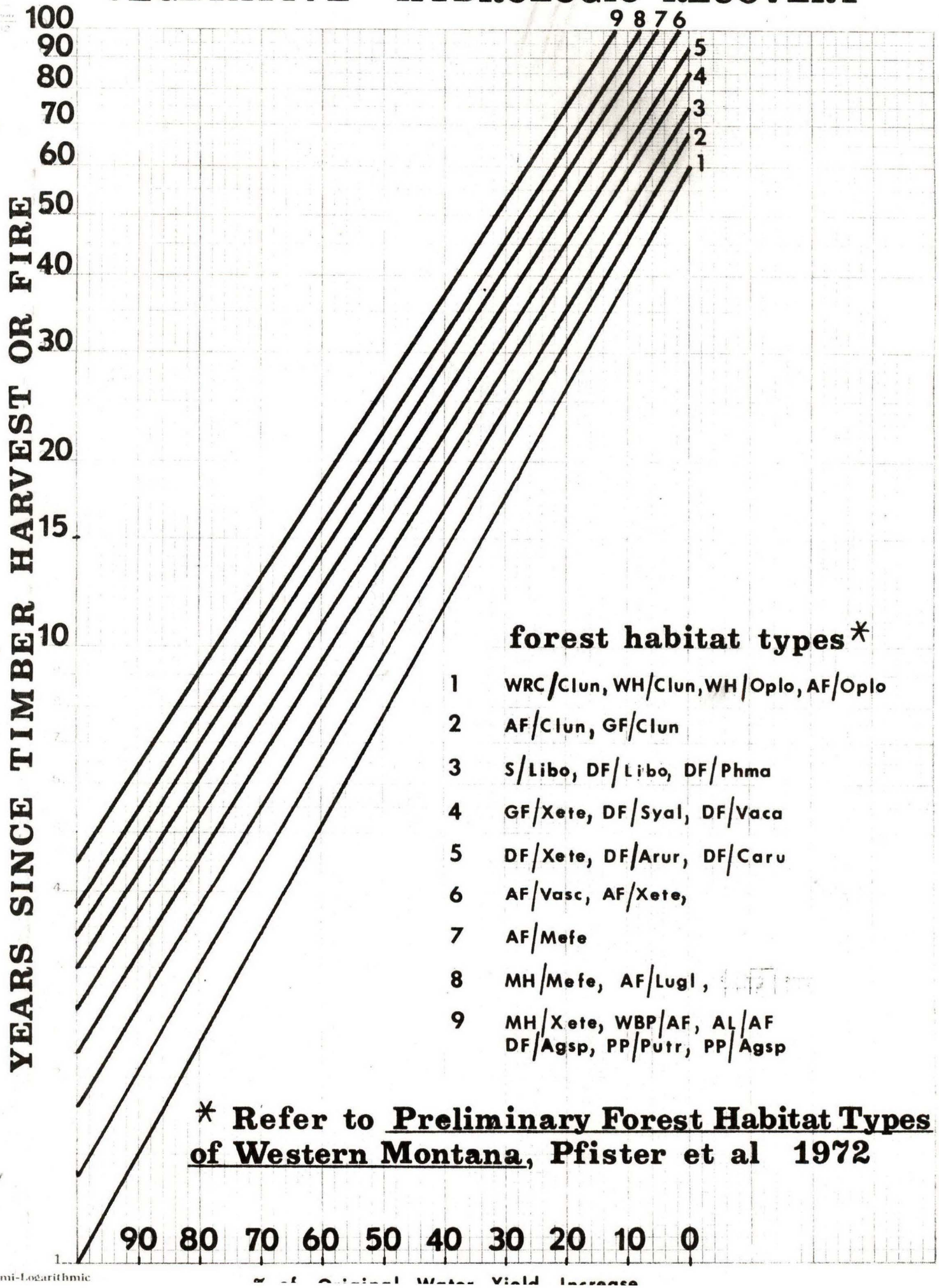


Figure 4 . .

# TIMBER HARVEST OTHER THAN CLEARCUT



gure 5 . . **VEGETATIVE – HYDROLOGIC RECOVERY**




* Refer to Preliminary Forest Habitat Types of Western Montana, Pfister et al 1972

Semi-Logarithmic

longer than transpiration recovery, being dependent upon tree height rather than canopy closure. The forest habitat types are shown in order of vegetative recovery. The order of forest habitat types and the timing of recovery is based upon field observations made by foresters, silviculture specialists, and the author on the Kootenai National Forest.

## Description and Examples of the Water Yield Analysis Procedure

The end result of the water yield analysis procedure is a calculation of the maximum probable increase in the average annual flow due to timber harvest or fire. Two items need to be determined, therefore;

1. The average annual runoff under "normal" conditions, which is interpreted as full vegetative cover.
2. The increase in runoff due to past timber harvest, fire, etc., plus the proposed timber sale.

The average runoff is calculated as follows:

1. Isolines of equal precipitation are transferred from the SCS precipitation map of the Kalispell quadrangle to the watershed in question. The procedure is designed for 3rd and 4th order watersheds (See Appendix 1 for an explanation of watershed order).
2. Planimeter the area between the precipitation isolines; an interval of five inches precipitation is sufficient.
3. Convert precipitation to runoff by use of Figure 2.
4. Calculate runoff by multiplying step 2 by step 3.

The maximum probable increase in runoff due to timber harvesting or fire is calculated by reference to Figures 3, 4, and 5. A few examples should clarify the use of the procedure.

### Schrieber Creek Watershed

The information needed is--what increase in water yield due to timber harvest took place in 1966 and 1973. The series of overlays which follow this page give the basic data needed to perform a water yield analysis on the Schrieber Creek Watershed. As can be seen on the Timber Harvest overlay, the 25 and 30 inch precipitation isolines are given. To calculate the average annual runoff prior to any timber harvesting (there was no recent fire in the watershed) the steps outlined above are followed.

#### Precipitation above 30"

1. Use 33" as average for this zone.
2. Area = 294 ac.
3. Runoff @ 33" = 1.0 acre feet/acre (Figure 2)
4. Runoff for zone = (294) x (1.0) = 294 acre feet

Precipitation 30" - 25"

1. Use 27.5" as average
2. Area = 916 ac.
3. Runoff @ 27.5 = 0.8 AF/A
4. Runoff = (916) x (0.8) = 733 AF

Precipitation below 25"

1. Use 22.5 as average
2. Area = 38 ac.
3. Runoff @ 22.5" = 0.6 AF/A
4. Runoff = (38) x (0.6) = 23 AF

Total Runoff for Schrieber Creek = (294) + (733) + (23) = 1050 AF

The next step is to calculate the increase in water yield due to timber harvesting as of 1966. The area shown as a partial cut was "highgraded" in the 1920's, and in 1962 a stand improvement cut was made which reduced approximately 40% of the basal area. Complete hydrologic recovery has taken place since the 1920 logging. The area covered by the partial cut is 390 acres and can be compared to a shelterwood method.

Figure 4 shows that a 40% basal area reduction is equivalent to 20% of the area being clearcut, or;

(390 acres) x (.2) = 78 acres equivalent clearcut.

The land type map shows that approximately 20% occurs in the 504-304 type which is in Group 1 (2' or less) on Figure 3. From this graph at the 5000' elevation, the increase in water yield is 0.5 acre-feet/acre so that;

(78 ac.) x (20%) x (0.5 AF/A) = 8 AF in 1962.

Likewise for the remaining 80% with land types in Group 3, and mainly above 3900' elevation, Figure 3 shows the increase in water yield is;

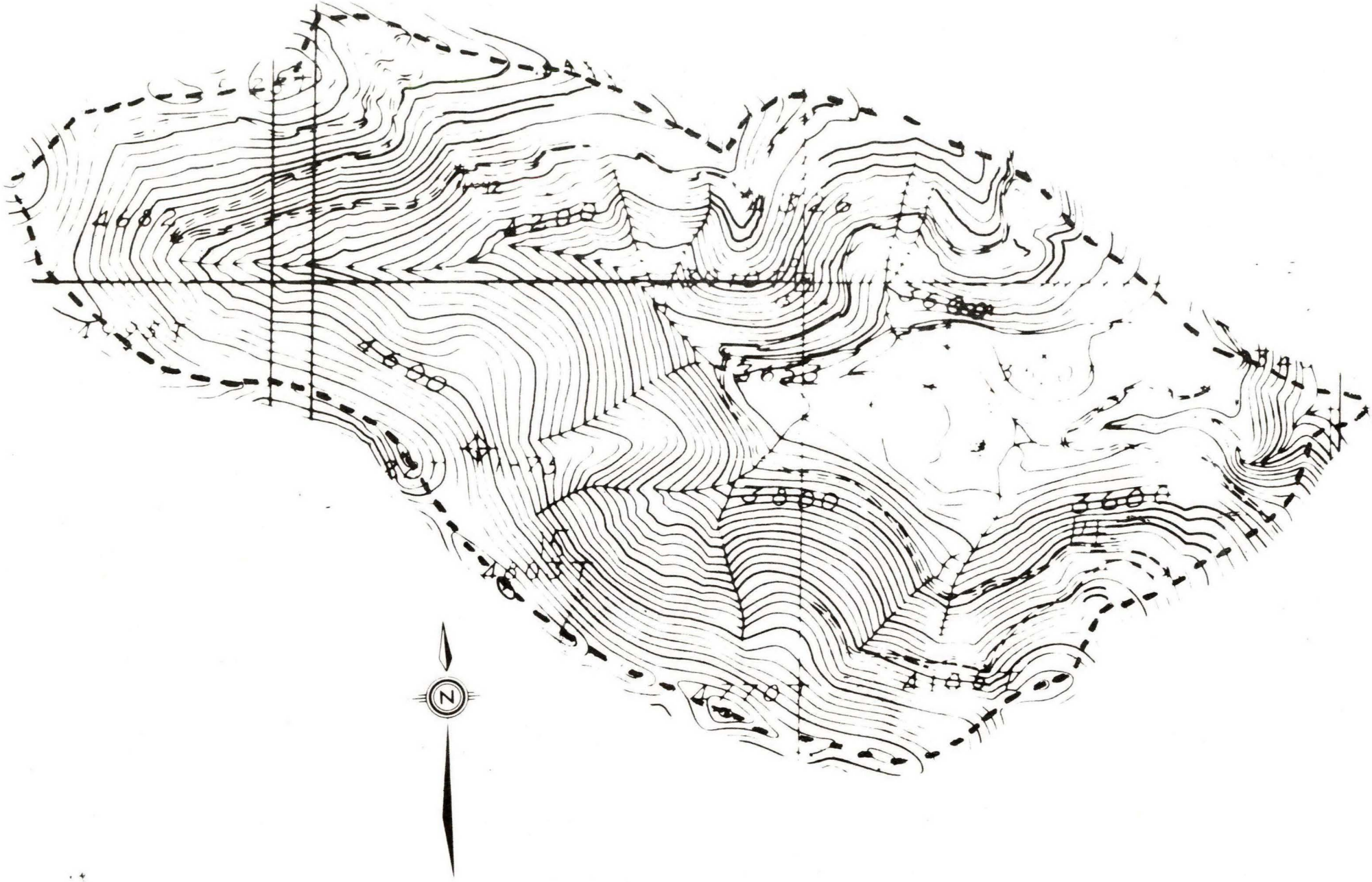
(78 ac.) x (80%) x (1.3 AF/A) = 81 AF in 1962.

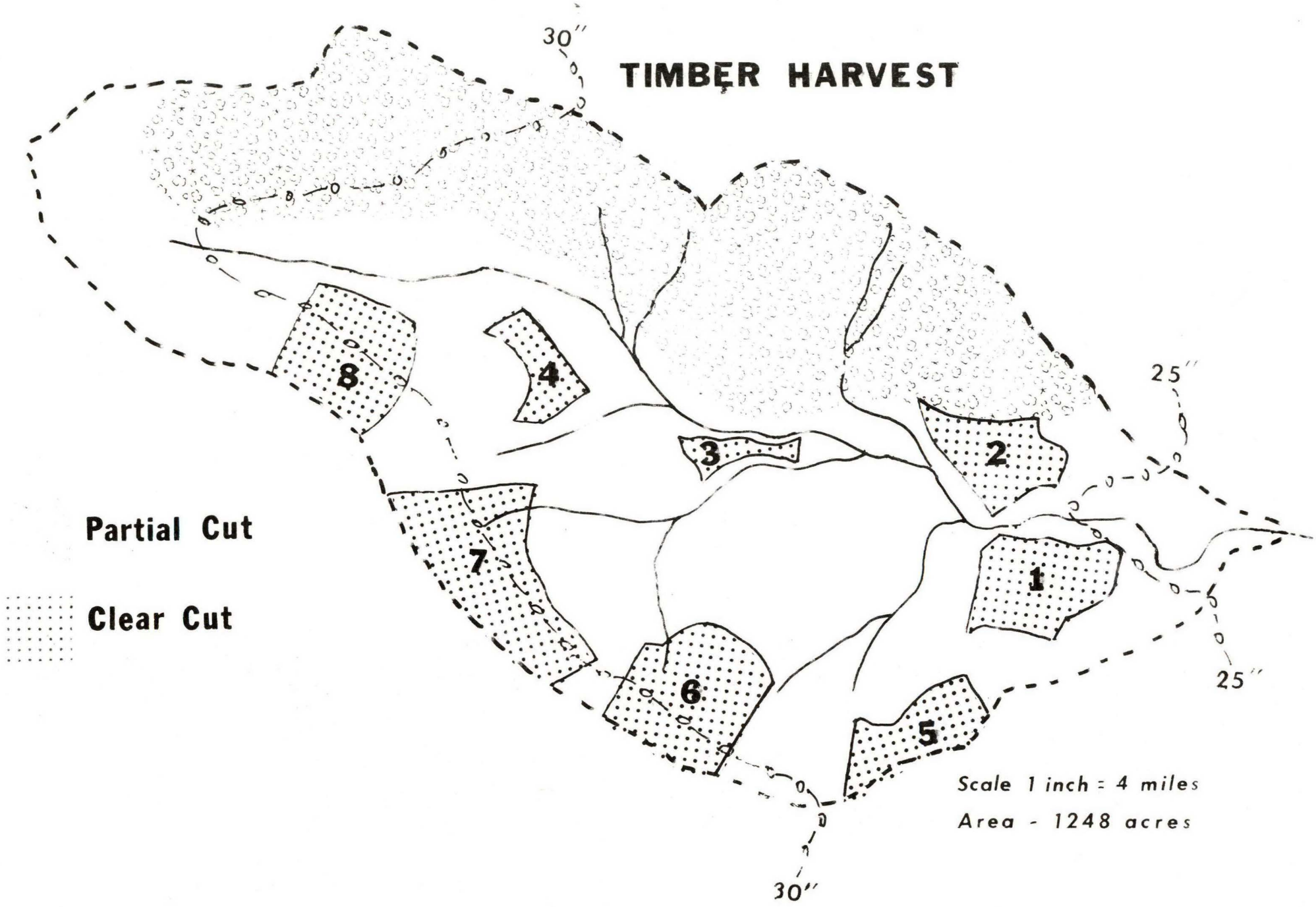
The total increase in water yield from the partial cut area in 1962 is;

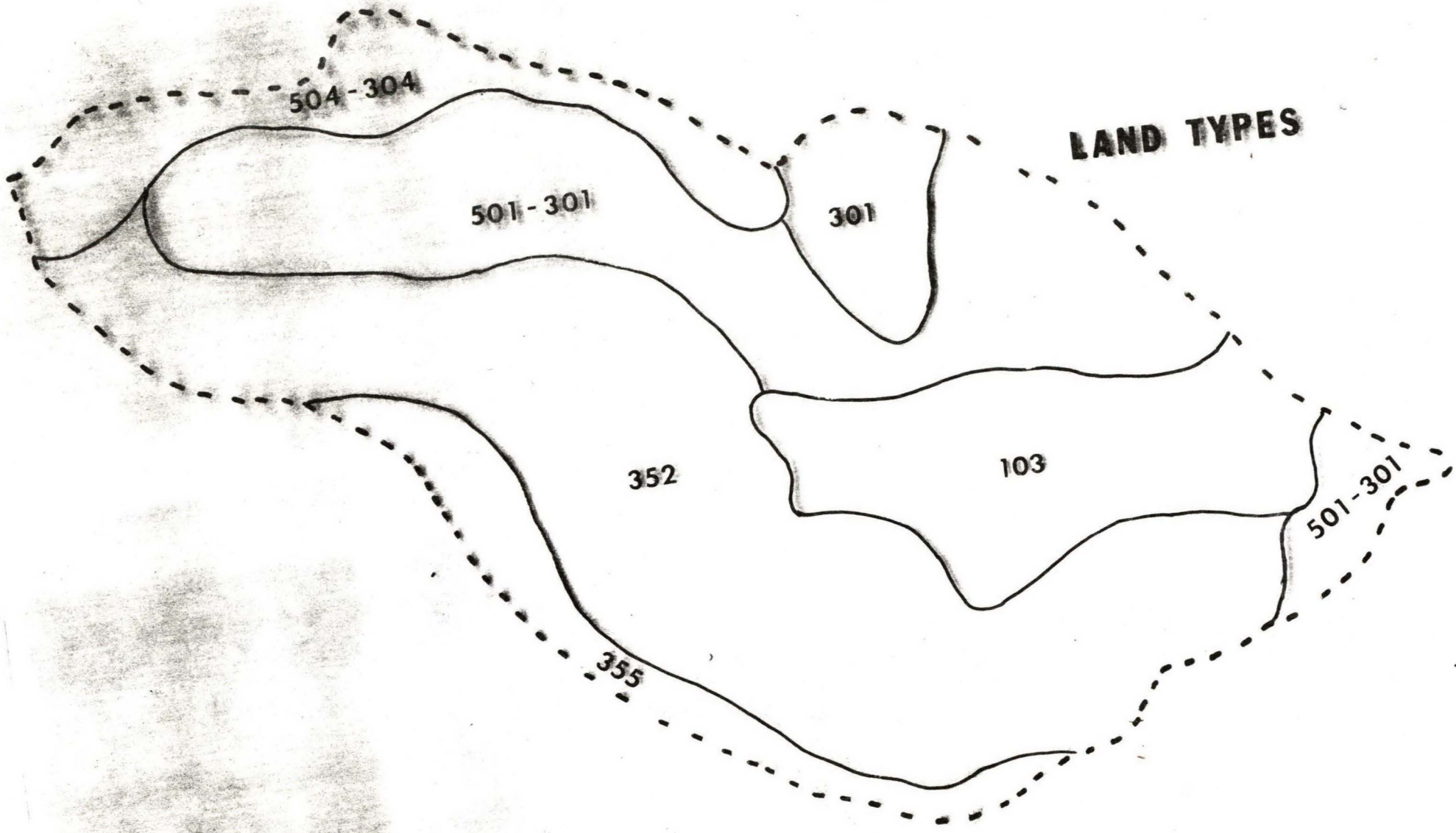
(81 AF) + (8 AF) = 89AF

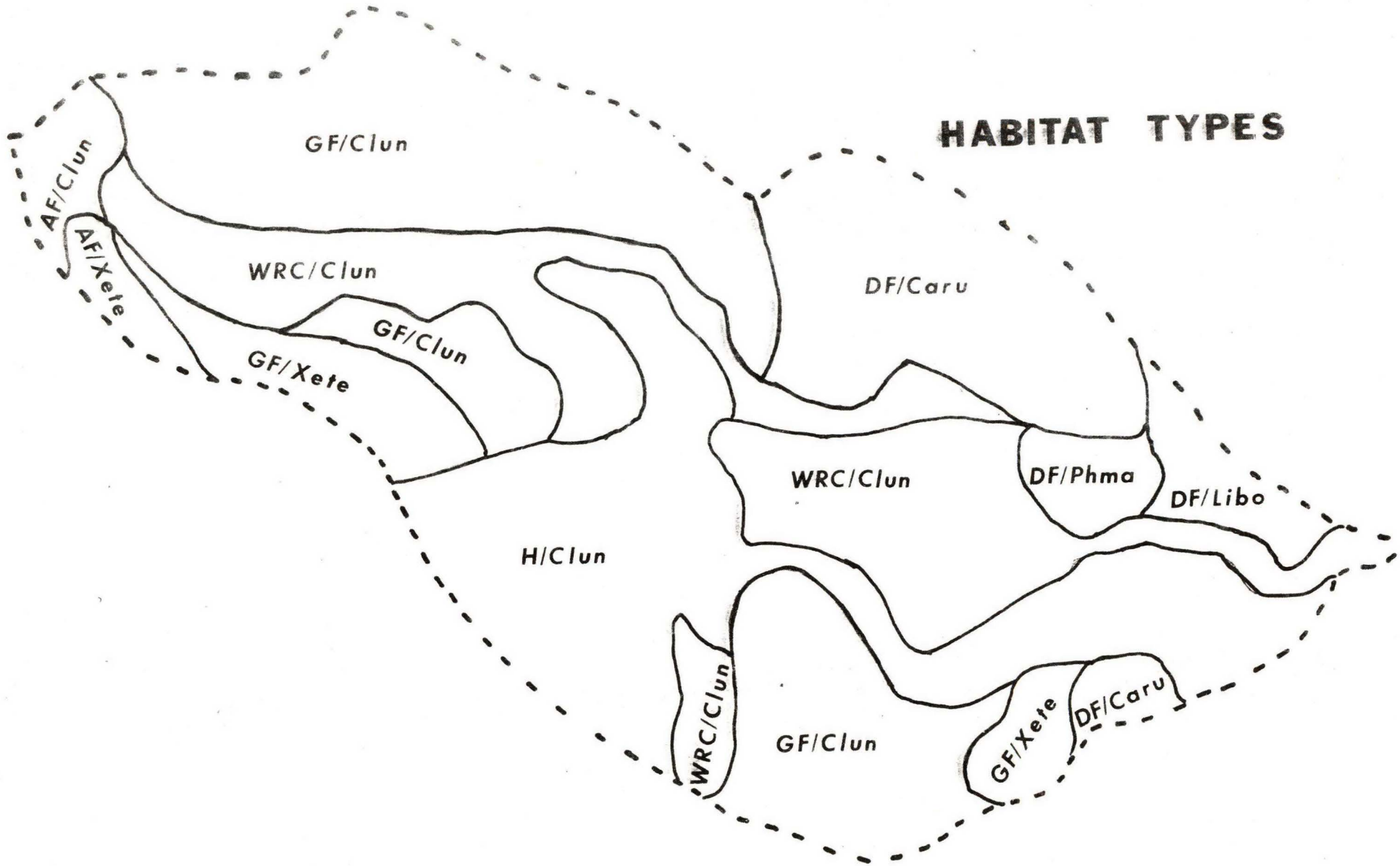
By 1966 a certain amount of recovery had taken place. About 30% of the partial cut is in the DF/Caru habitat type and the remaining 70% in the

SCHRIEBER CREEK WATERSH




TIMBER HARVEST
30"
25"
25"
30"
8
4
3
2
7
1
6
5
Partial Cut
Clear Cut
Scale 1 inch = 4 miles
Area - 1248 acres


LAND TYPES
504 - 304
501 - 301
301
352
103
501 - 301
355


HABITAT TYPES
GF/Clun
AF/Clun
AF/Xete
WRC/Clun
GF/Clun
GF/Xete
DF/Caru
WRC/Clun
DF/Phma
DF/Libo
H/Clun
WRC/Clun
GF/Clun
GF/Xete
DF/Caru

GF/Clun habitat type. GF/Clun has a more rapid recovery than DF/Caru. To take this difference into account GF/Clun is read on line 2, Figure 5, so that in 4 years 74% of the original increase in water yield remains. DF/Caru is read on line 5 which gives 87% of the original water yield increase after 4 years. These two recovery rates can be combined as follows:

DF/Caru: (87%) x (30%) = 26.1%
GF/Clun: (74%) x (70%) = 51.8%
Combined recovery = 77.9 or 78%

The water yield increase for the partial cut in 1966 is therefore;

(89 AF) x (78%) = 69 AF

The numbered clearcut units were cut in 1965 so that in 1966 the maximum increase took place. Looking at cutting unit #1, it is seen that the unit lies at an average elevation of approximately 3600' and occurs on a land type in Group 3. Figure 3 shows the increase to be 1.15 feet per acre. The area of the cutting unit is 31 acres so that the increase in water yield is;

(31 ac.) x (1.15 AF/A) = 36AF

A table can be constructed for the cutting units to show this information:

| Unit | Land Type | Elevation | Area | AF/Ac. | AF |
|---|---|---|---|---|---|
| 1 | 352 | 3600 | 31 | 1.15 | 36 |
| 2 | 103 | 3450 | 30 | 1.10 | 33 |
| 3 | 103 | 3600 | 13 | 1.15 | 15 |
| 4 | 352 | 4200 | 18 | 1.30 | 23 |
| 5 | 352 | 4200 | 21 | 1.30 | 27 |
| 6 | 352 | 4400 | 23 | 1.30 | 30 |
| 6 | 355 | 4700 | 10 | 0.90 | 9 |
| 7 | 352 | 4500 | 12 | 1.30 | 16 |
| 7 | 355 | 4700 | 15 | 0.90 | 13 |
| 8 | 352 | 4600 | 24 | 1.30 | 31 |
| 8 | 355 | 4700 | 12 | 0.90 | 11 |
| | | | | Total | 244 |

The area taken up by roads also adds to the water yield increase and the area in roads was calculated as 12 acres so that;

(12 ac.) x (1.3 AF/A) = 16 AF

It is now possible to determine the maximum probable increase in water yield due to timber harvesting as of 1966;

| | AF |
|---|---|
| Partial Cut | 69 |
| Clearcut | 244 |
| Roads | 16 |
| Total: | 329 acre feet |

The percentage increase above the "normal", average annual runoff is;

(329/1050) x (100) = 31%

By 1973 further hydrologic recovery has taken place so that the increase in water yield should be less than the 31% in 1966. For the partial cut area 11 years have elapsed since cutting and the recovery is from Figure 5.

DF/Caru: (60%) x (30%) = 18.0

GF/Clun: (49%) x (70%) = 34.3

Combined Recovery = 52.3 or 52%

and the increase in water yield is:

(89 AF) x (52%) = 46 AF

For the clearcut units the same procedure is followed except recovery has taken place for only 6 years rather than 11. Cutting unit #1 occurs in a GF/Clun habitat type which has only 63%, Figure 5, of the original increase in water yield of 1966 or,

(36 AF) x (.63) = 23 AF

The following table summarizes this information for all the cutting units;

| Unit | Habitat Type | Recovery Percentage | Original Increase | AF |
|---|---|---|---|---|
| 1 | GF/Clun | .63 | 36 | 23 |
| 2 | DF/Phma | .71 | 33 | 23 |
| 3 | WRC/Clun | .56 | 15 | 8 |
| 4 | WRC/Clun | .56 | 23 | 13 |
| 5 | GF/Xete | .72 | 19 | 14 |
| 5 | GF/Clun | .63 | 8 | 5 |
| 6 | WRC/Clun | .56 | 12 | 7 |
| 6 | GF/Clun | .63 | 27 | 17 |
| 7 | H/Clun | .56 | 29 | 16 |
| 8 | GF/Clun | .63 | 13 | 8 |
| 8 | GF/Xete | .72 | 29 | 21 |
| | | | Total: | 155 |

The maximum probable increase in water yield as of 1973 is:

| | AF |
|---|---|
| Partial Cut | 46 |
| Clearcut | 155 |
| Roads | 16 |
| Total: | 217 |

and the percentage increase is;

(217/1050) x (100) = 21%

The water yield analysis procedure has demonstrated that in 1966, just after the completion of the timber sale, the maximum probable increase was on the order of 329 acre feet, or 31% above the average annual. Six years later the increase had dropped to 217 acre feet or 21% of the annual average due to the revegetation of the area by shrubs and seedlings.

Hypothetical Examples

The Schrieber Creek watershed and existing cutting pattern will be used in a hypothetical example to illustrate many of the possibilities which could be encountered when applying the procedure. The following timber

sale is planned for the watershed:

1. Units 1 and 2 were clearcut in 1953.
2. Unit 3 is planned for a seed tree cut removing 90% of the basal area.
3. Units 4 and 5 will have a shelterwood cut removing 50% of the basal area.
4. Unit 6 will be clearcut.
5. Units 7 and 8 will have the overstory removed, reducing the basal area by 25%.
6. The area shown as partial cut will have a commercial thinning, removing 60% of the basal area of a 1910 fire stand.
7. From a watershed condition and channel stability survey it has been determined that the watershed can sustain a 16% increase in water yield.

The average annual runoff, "normal", has been previously calculated as 1050 acre-feet. The increase in water yield due to the past timber harvesting of cutting unit 1 and 2 is:

| Unit | Habitat Type | Years | Recovery Percentage | Original Inc. | AF |
|---|---|---|---|---|---|
| 1 | GF/Clun | 20 | .33 | 36 | 12 |
| 2 | DF/Phma | 20 | .40 | 33 | 13 |
| | | | | Total: | 25 |

The increase due to the proposed timber sale is summarized below:

| Unit | Land Type | S.R. 1/ | ECC% 2/ | Acres | ECC 2/ | AF/Ac. | AF |
|---|---|---|---|---|---|---|---|
| 3 | 103 | 90% | 100 | 13 | 13 | 1.15 | 15 |
| 4 | 352 | 50% | 40 | 18 | 7 | 1.30 | 9 |
| 5 | 352 | 50% | 40 | 21 | 8 | 1.30 | 10 |
| 6 | 352 | 100% | 100 | 23 | 23 | 1.30 | 30 |
| 6 | 355 | 100% | 100 | 10 | 10 | 0.90 | 9 |
| 7 | 352 | 25% | 0 | 29 | 0 | 0 | 0 |
| 8 | 352 | 25% | 0 | 42 | 0 | 0 | 0 |
| | | | | | | Total: | 73 |

1/ S.R. means stand reduction, Figure 4.

2/ ECC% means percent equivalent clearcut, Figure 4.

Partial Cut

| Area | S.R. | AF/Ac. 1/ | AF |
|---|---|---|---|
| 390 | 60% | 0.15 | 58 |

1/ From Figure 4.

The total increase in water yield which can be anticipated as a result of the proposed timber sale is;

| | AF |
|---|---|
| Past Clearcutting | 25 |
| Proposed Cutting Units | 73 |
| Commercial Thinning | 58 |
| Roads | 6 |
| Total: | 162 |

The percentage increase is (162/1050) x (100) = 15.4% which is within the 16% limit imposed upon this watershed.

The question of how much acreage could be cut over in a watershed with a given percent limitation to the increase in water yield can be determined by applying this equation:

A = PY/R where

P = the % limit

Y = average annual runoff

R = average increase in AF/Ac.

For the Schrieber Creek watershed using a percentage limit of 12%, an average annual runoff of 1050 acre-feet, and an average increase of 1.2 AF/Ac., the maximum acreage in equivalent clearcut is;

$$A = \frac{(.12)\ (1050)}{1.2} = 105 \text{ acres}$$

For planning purposes it may be necessary to know how much acreage would be available in a watershed after a certain period of time has elapsed following timber harvesting. Using the hypothetical example, after 10 years the increase due to commercial thinning has completely recovered and the increase due to roads has remained the same. The increase from the cutting units is:

| Unit | Habitat Type | Years | Recovery Percentage | Original Increase | AF |
|---|---|---|---|---|---|
| 1 | GF/Clun | 30 | .22 | 36 | 8 |
| 2 | DF/Phma | 30 | .28 | 33 | 9 |
| 3 | WRC/Clun | 10 | .44 | 15 | 7 |
| 4 | WRC/Clun | 10 | .44 | 5 | 2 |
| 5 | GF/Xete | 10 | .56 | 5 | 3 |
| 6 | WRC/Clun | 10 | .44 | 12 | 5 |
| 6 | GF/Clun | 10 | .52 | 28 | 15 |
| | | | | Total: | 49 |

The total increase in water yield is:

| | | AF |
|---|---|---|
| Past Cutting | | 49 |
| Roads | | 6 |
| | Total: | 55 |

The limit of 16% of acre-foot increase is;

(.16) x (1050) = 168 AF

By subtracting the present increase from the limit and dividing by the average increase for the watershed, the acreage available in 10 years is;

(168) - (55) = 113 AF ÷ 1.2 AF/Ac. = 97 acres (ECC)

The Lower Order Watersheds

Although the water yield analysis is intended for use in third or fourth order watersheds, the smaller order watersheds also require some restriction upon the area to be cut over at any one time. A good example of the need for restraint is the side drainage on the West Fork of Quartz Creek which gullied badly for two successive years after the 100-125 acre watershed had been clearcut. Since there is no research nor barometer watershed studies which can be used to guide timber harvesting of first and second order watersheds, the table below, based upon the author's observations, is offered as guidance.

Maximum Area In Clearcut Condition

| | Aspect | |
|---|---|---|
| | N and E | S and W |
| 1st Order | 80% | 60% |
| 2nd Order | 60% | 40% |

Vegetation Manipulation and Peak Flows

Considering the importance of the subject, surprisingly little is known about the effects of vegetation removal upon peak discharge, but there is sufficient evidence to show that tree removal has increased peak flows significantly (13), (15), (18), (19). Because the processes controlling the effects of tree removal on peak discharge are not understood as well as those contributing to increases in total streamflow, more importance will be given to the calculation of increases in total annual stream flow.

Recent work at the Benton Creek experimental watershed, Priest River, Idaho, has shown that clearcut areas on southerly aspects have melted out 3 - 4 weeks earlier than adjacent forested areas on the same slope (20). This acceleration of the snowmelt, particularly at lower elevations in the watershed, will cause those south aspect cutting units to release water to streamflow prior to the peak runoff period for the watershed. The net result of this change in the melt pattern is that although an increase in the total flow has taken place, this increase will occur at a time when the channel has more cross sectional area to accommodate the flow. By this line of reasoning the increase in flow will have less erosive potential than if it had taken place during the peak discharge period. The change in melt pattern can be taken into effect in a water yield analysis. The impact from a certain increase in the total annual flow is not so great if a portion of this increase takes place before the peak discharge period. For example, a watershed in which the increase from timber harvesting is 15% may not exceed the capacity of the channel system if 5% of the increase comes prior to the peak. As a guideline in evaluating the effect on peak flow consider that the timing of snowmelt will be ad-

vanced sufficiently so as not to occur during the peak runoff period if:

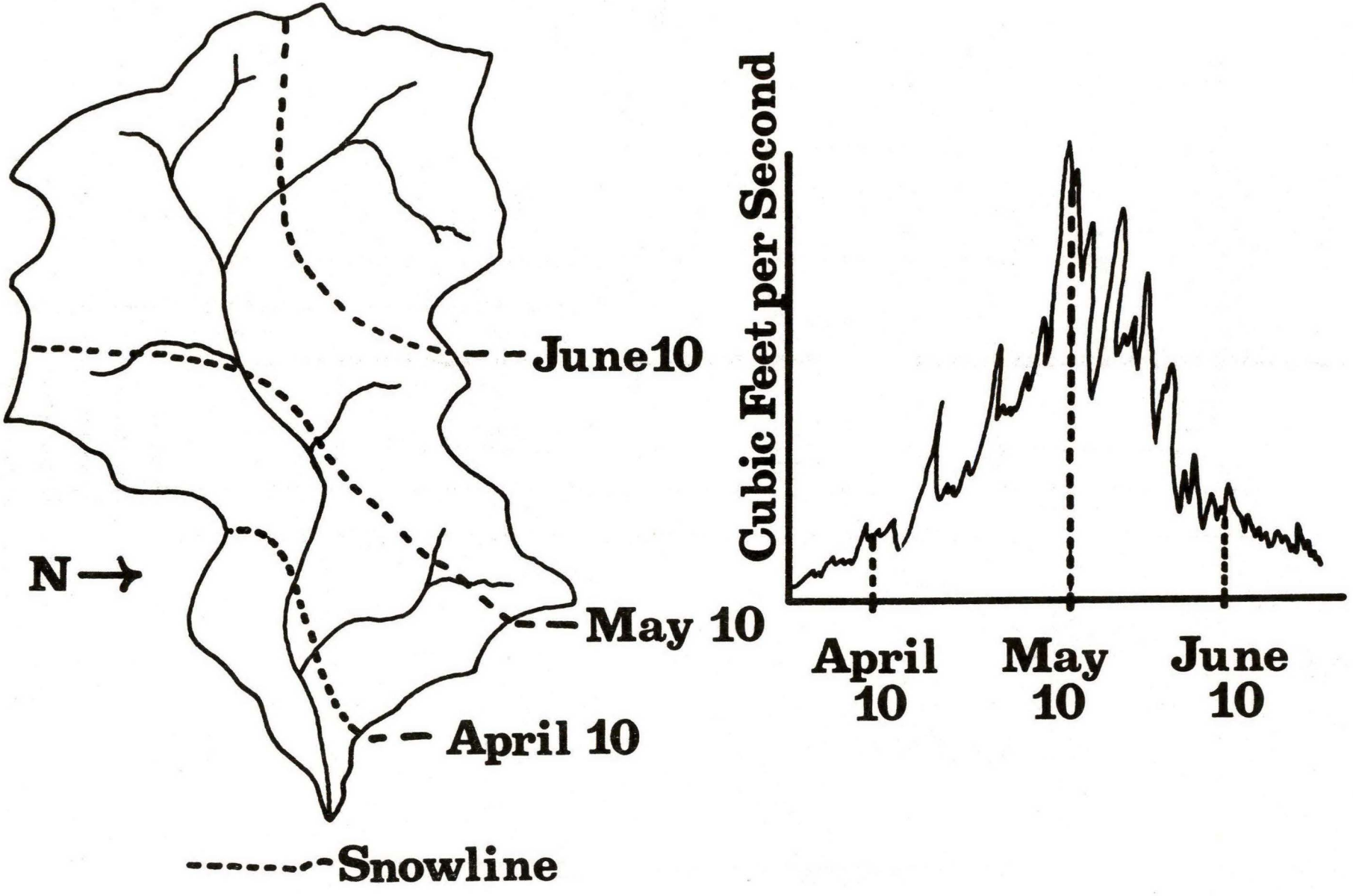
1. the unit is clearcut.
2. the unit is located below the mid-elevation of the watershed.
3. the unit is located between 135 and 225 degrees of south aspect.

The Benton Creek study also showed that on the north aspect there was no change in the timing of the melt following clearcutting. This finding is open to more question than the south aspect results for a variety of reasons but does illustrate the fact that there undoubtedly are areas within a watershed which will melt out later than the peak discharge period. Increased flows from cutting units in these locations again will have less channel impact than if the increase came during the peak runoff period for the watershed. The Soil Conservation Service snow survey personnel have observed a retreat of the snowline in any watershed to approximately the same position each year during the peak discharge period. Areas which are considerably higher than this snowline and on north aspects will have most of the snow pack remaining during the peak discharge period for the watershed. This snow distribution pattern is shown in Figure 6. Cutting units which occur in this high elevation, north aspect zone can be evaluated as contributing an increase in flow after the peak discharge period for the watershed. As a guideline this high elevation, north aspect zone is defined as occurring:

1. in the highest ¼ elevation zone of the watershed.
2. between 315 and 45 degrees of north aspect.

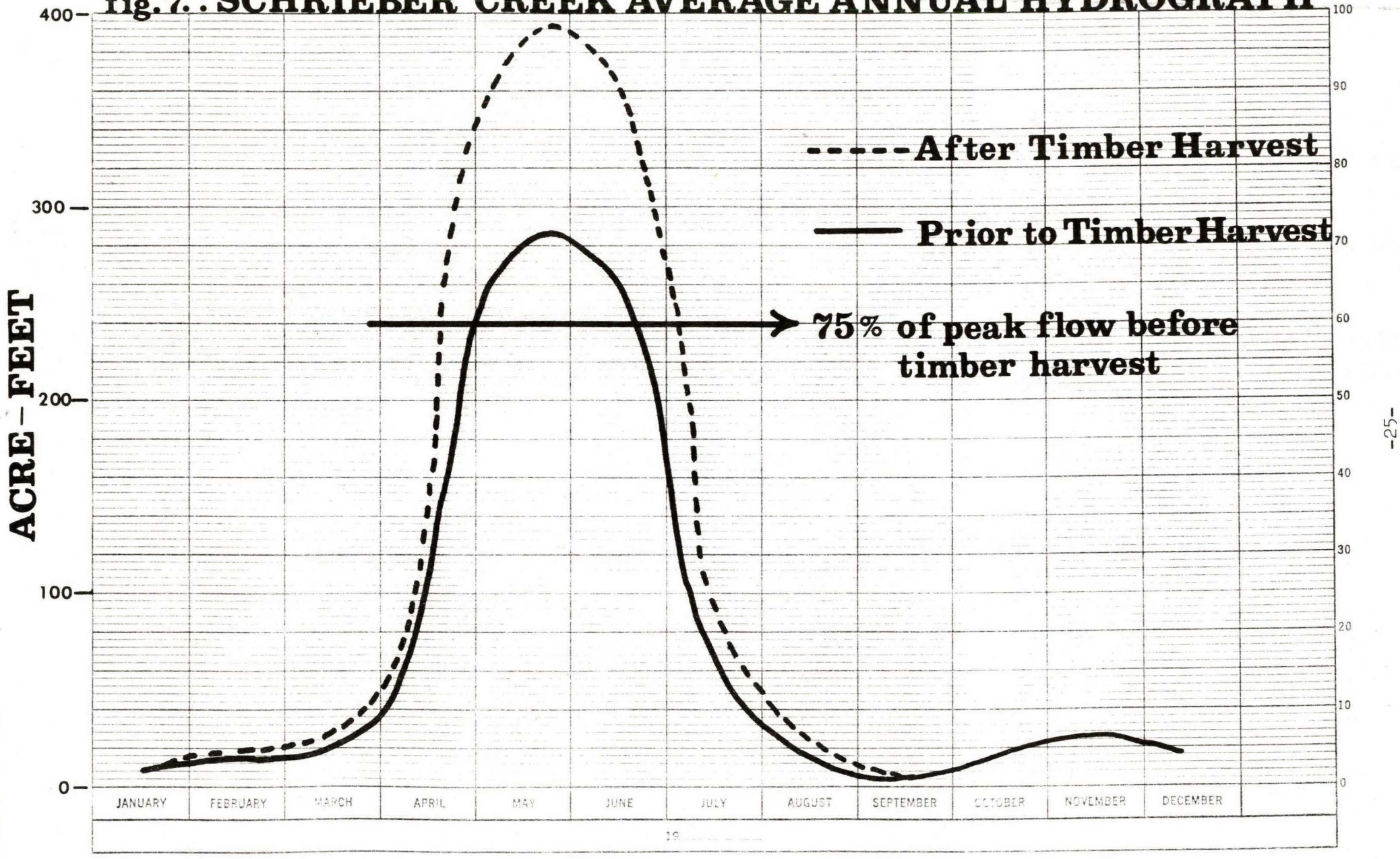
Increasing the peak flow can affect the erosion and sediment production in a watershed by enlarging the duration of flow conditions which have the potential for scouring the channel bed, undercutting the channel banks, and transporting large amounts of sediment. The

Fig. 6 . . Retreat of snowline and corresponding hydrograph for a hypothetical watershed.



change in the watershed average monthly hydrograph is shown in Figure 7 for Schrieber Creek using the previous hypothetical example. The horizontal line, which bisects the hydrograph before and after timber harvest, indicates 75% of the peak flow before cutting and defines a channel impact period. Flows above this amount are responsible for most of the erosive power of the stream. The increased flows have lengthened this channel impact period by nearly 50% in this example. In order to analyze the effect on the channel impact period it is necessary to reconstruct the annual hydrograph from the water yield analysis in the first section which gives the total average annual flow and increase from timber harvesting or fire. The hydrograph can be approximated by using a known hydrograph of the most similar watershed available. The flow records taken on the district from 1963-1965 can be used for this purpose. By plotting the hydrograph from these records the proportion or percentage of each month to the total anual flow can be calculated. These monthly percentages are then aplied to the average annual flow of the watershed in question. If a USGS gaging station, such as those on Flower, Young, Pinkham, or Big Creek, is available then these records can also be used to develop a hydrograph.

# fig.7. . SCHRIEBER CREEK AVERAGE ANNUAL HYDROGRAPH



Channel Stability Evaluation

In response to the need for an inventory of the stream channel stability, the hydrologists of Region One have developed a Channel Stability Rating procedure from an approach originated by Dr. Walter F. Megahan. The discussion which follows describes this procedure:

The most sensitive and reliable indicator of a watershed's response to its past history, whether of fire, timber harvest, flood or placer dredging, is the stream channel. Certain features of the stream bed and bank are produced by the flow regime of the watershed (21). It also is apparent that some physical characteristics of the channel determine the resistance to flow or, in other words, the stability of the channel. An examination of these stability indicators in the field will enable the land manager to evaluate the relative stability of the channel system. The basic questions to be answered are:

1. What effect have past flows had upon the channel?

2. How resistant are the channel banks and bed to detachment?

3. What is the sediment potential of the channel system?

These three questions are all related by the stability indicators shown in Figure 8. The first indicator, landform slope, refers to the gradient of the upper bank. The diagram on the reverse side of Figure 8 shows the positions of upper and lower banks relative to the channel bottom for a typical cross section. The steeper the slope of the upper bank, the greater the potential for slumping if undercut and the more material which can reach average high water line by the process of surface creep.

The next item, mass wasting, draws attention to observable slumping which has taken place in the past. Debris jam potential is self-explanatory. In evaluating streamside vegetation, emphasis is placed upon the root system. For this reason trees and shrubs whose root systems are deeper and more extensive rate higher than forbs and grasses.

FIGURE 8

USDA-FOREST SERVICE

## R-1 STREAM CHANNEL STABILITY FIELD EVALUATION FORM

| Item Rated | Stability Indicators by Classes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| UPPER BANKS | EXCELLENT | | GOOD | | FAIR | | POOR | |
| Landform Slope | Bank slope gradient <30% | (2) | Bank slope gradient 30-40% | (4) | Bank slope gradient 40-60% | (6) | Bank slope gradient 60% + | (8) |
| Mass Wasting (Existing or Potential) | No evidence of past or potential for future mass wasting into channels. | (3) | Infrequent and/or very small. Mostly healed over. Low future potential. | (6) | Moderate frequency & size, with some raw spots eroded by water during high flows. | (9) | Frequent or large, causing sediment nearly yearlong OR imminent danger of same. | (12) |
| Debris Jam Potential (Floatable Objects) | Essentially absent from immediate channel area. | (2) | Present but mostly small twigs and limbs. | (4) | Present, volume and size are both increasing. | (6) | Moderate to heavy amounts, predominantly larger sizes. | (8) |
| Bank Protection from Vegetation | 90% + plant density. Vigor and variety suggests a deep, dense root mass. | (3) | 70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass. | (6) | 50-70% density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass. | (9) | <50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass. | (12) |
| LOWER BANKS | | | | | | | | |
| Channel Capacity | Ample for present plus some increases. Peak flows contained, W/D ratio <7. | (1) | Adequate. Overbank flows rare. Width to Depth (W/D) ratio 8-15. | (2) | Barely contains present peaks. Occasional overbank floods. W/D ratio 15-25. | (3) | Inadequate. Overbank flows common. W/D ratio >25. | (4) |
| Bank Rock Content | 65% + with large, angular boulders 12" + numerous. | (2) | 40 to 65%, mostly small boulders to cobble 6-12". | (4) | 20 to 40% , with most in the 3-6" diameter class. | (6) | <20% rock fragments of gravel sizes, 1-3" or less. | (8) |
| Obstructions Flow Deflectors Sediment Traps | Rocks, old logs firmly embedded. Flow pattern of pool & riffles stable without cutting or deposition. | (2) | Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm. | (4) | Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting and filling of pools. | (6) | Frequent obstructions and deflectors cause bank erosion yearlong. Sed. traps full, channel migration occuring. | (8) |
| Cutting | Little or none evident. Infrequent raw banks less than 6" high generally. | (4) | Some, intermittently at outcurves & constrictions. Raw banks may be up to 12". | (8) | Significant. Cuts 12"-24" high. Root mat overhangs and sloughing evident. | (12) | Almost continuous cuts, some over 24" high. Failure of overhangs frequent. | (16) |
| Deposition | Little or no enlargement of channel or point bars. | (4) | Some new increas in bar formation, most from coarse gravels. | (8) | Moderate deposition of new gravel & coarse sand on old and some new bars. | (12) | Extensive deposits of predominately fine particles. Accelerated bar development. | (16) |
| BOTTOM | | | | | | | | |
| Rock Angularity | Sharp edges and corners, plane surfaces roughened. | (1) | Rounded corners & edges, surfaces smooth & flat. | (2) | Corners & edges well rounded in two dimensions. | (3) | Well rounded in all dimensions, surfaces smooth. | (4) |
| Brightness | Surfaces dull, darkened, or stained. Gen. not "bright". | (1) | Mostly dull but may have up to 35% bright surfaces. | (2) | Mixture, 50-50% dull and bright, ± 15%, ie 35-65%. | (3) | Predominately bright, 65% +, exposed or scoured surfaces. | (4) |
| Consolidation or Particle Packing | Assorted sizes tightly packed and/or overlapping. | (2) | Moderately packed with some overlapping. | (4) | Mostly a loose assortment with no apparent overlap. | (6) | No packing evident. Loose assortment, easily moved. | (8) |
| Bottom Size Distribution & Percent Stable Materials | No change in sizes evident. Stable materials 80-100%. | (4) | Distribution shift slight. Stable materials 50-80%. | (8) | Moderate change in sizes. Stable materials 20-50%. | (12) | Marked distribution change. Stable materials 0-20%. | (16) |
| Scouring and Deposition | Less than 5% of the bottom affected by scouring and deposition. | (6) | 5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools. | (12) | 30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools. | (18) | More than 50% of the bottom in a state of flux or change nearly yearlong. | (24) |
| Clinging Aquatic Vegetation (Moss & Algae) | Abundant. Growth largely moss like, dark green, perennial. In swift water too. | (1) | Common. Algal forms in low velocity & pool areas. Moss here too and swifter waters. | (2) | Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick. | (3) | Perennial types scarce or absent. Yellow-green, short term bloom may be present. | (4) |
| COLUMN TOTALS → | | | | | | | | |

Add the values in each column for a total reach score here. (E.____+ G.____+ F.____+ P.____= _____).

Reach score of: <38=Excellent, 39-76=Good, 77-114= Fair, 115+=Poor.

R1-2500-5 (6/73)

OVER

## R-1 STREAM REACH INVENTORY and CHANNEL STABILITY EVALUATION

LOCATION

Forest Name_____ & No._____ Ranger Dist._____ Survey Date_____

Observer(s)_____ Stream Name_____

Reach Description & Other Identification_____

Aerial Photo No._____ Coordinates & Identification_____ P.W.I. W/S No._____

INVENTORY MEASUREMENTS & ESTIMATES*

Stream Size & Discharge Survey Date At Maximum Width_____Ft._____Ft.* Ave.Depth _____Ft._____Ft.* Velocity _____f/s_____f/s* Discharge _____cfs_____cfs*

Gradient_____% Sinuosity ratio_____ Stream Order_____ Turbidity Level_____ Stream Stage_____

Channel Flow Pattern_____

Soils Description_____

Landform and/or Geologic Type_____

Vegetative Type_____

Number of debris jams &/or fish blocks/mile_____. Upstream watershed impacts (Types)_____

Size Composition of Bottom Materials (Total to 100%)

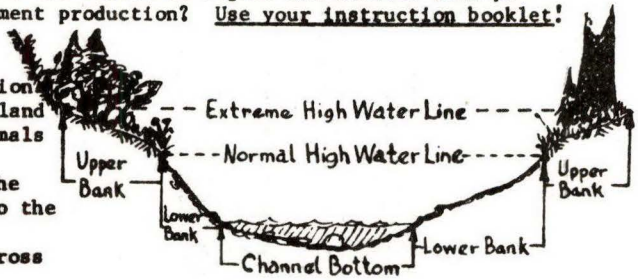
1. Exposed bedrock.....____%
2. Large boulders, 3' + Dia..____%
3. Small boulders, 1-3'.....____%
4. Large rubble, 6"-12".....____%
5. Small rubble, 3"-6".....____%
6. Coarse gravel, 1"-3".....____%
7. Fine gravel, 0.1"-1".....____%
8. Sand, silt, clay, muck...____%

Weather and Other Remarks _____

INSTRUCTIONS

Use a separate rating form for each length of stream that appears similar. Complete the inventory items above using maps, aerial photos, and field observations and measurements. On the opposite side of this page, the channel and adjacent flood plain banks are subjectively rated, item by item, following an on-the-ground inspection. Circle only one of the numbers in parentheses for each item rated. If actual conditions fall somewhere between the conditions as described, cross out the number given and below it write in an intermediate value which better expresses the situation. Don't key in on a single indicator or a small group of indicators but use them all for the most diagnostic value. The indicators are interrelated so don't dwell on any one item for long. Do the best you can and the pluses and minuses should balance out. Keep in mind that each item directly or indirectly seeks to answer three basic questions: (1) What are the magnitude of the hydraulic forces at work to detach and transport the various organic and inorganic bank and channel components? (2) How resistent are these components to the recent streamflow forces exerted on them? (3) What is the capacity of the stream to adjust and recover from potential changes in flow volume and/or increases in sediment production? Use your instruction booklet!

DEFINITION OF TERMS AND ILLUSTRATIONS

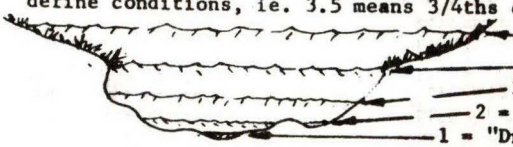



Upper Bank - That portion of the topographic cross section from the break in the general slope of the surrounding land to the normal high water line. Terrestrial plants & animals normally inhabit this area.

Lower Banks - The intermittently submerged portion of the channel cross section from the normal high water line to the water's edge during the summer low flow period.

Channel Bottom - The submerged portion of the channel cross section which is totally an aquatic environment.

Stream Stage - The height of water in the channel at the time of rating is recorded on the top half of this page using numbers 1 through 5. These numbers, as shown below, relate to the surface water elevation relative to the normal high water line. A decimal division should be used to more precisely define conditions, ie. 3.5 means 3/4ths of the channel banks are under water at the time of rating.



5 = Flooding. The flood plain is completely covered.
4 = High. Channel full to the normal high water line.
3 = Moderate. Bottom and ½ of lower banks wetted.
2 = Low. Bottom covered but very little of the lower banks wet.
1 = "Dry". Essentially no flow. Water may stand in bottom depressions.

* Use an asterisk behind all estimates that could be measured but weren't.

The W/D in the channel capacity row refers to the width/depth ratio of the channel at the normal high water level. Bank rock content, obstructions, and cutting items should be self-explanatory. Deposition should be judged from the standpoint of whether or not an acceleration of deposition above the normal is taking place. For example, if recent deposition has occurred in a place where ordinarily the flow would transport the material through the stretch of the channel, then active erosion upstream in the watershed is probably taking place.

The angularity and brightness items relate to the movement of material in the bed itself. Consolidation or particle packing refers to the roughness of the bottom to the direction of flow. Bottom size distribution and percent stable material are interrelated items and emphasis should be placed upon stable materials since detecting changes from a size distribution typical of the bedrock and flow regime of the watershed requires considerable subjective judgment. A reach of the stream should be rated for scouring and deposition rather than one cross section. Clinging vegetation is usually scarce in streams carrying a heavy sediment load.

It has been observed in the field and stands to reason that many of these stability indicators are interrelated. A stream which is out of equilibrium will often have most of the natural sediment traps full; exhibit frequent undercutting of its banks; have little particle packing in the bed which has a reduced amount of stable material; and scouring and deposition are common. By contrast, a stable stream usually has ample bank vegetation; an adequate channel capacity for flood flows; logs well-anchored into the sides and bottom; and few signs that recent deposition has taken place or that the gravels in the bottom have been moved during peak flows.

When a Channel Stability Rating is applied routinely to every third and fourth order portion of a stream channel within a timber sale area, after a year or two the District will have a record of channel stability conditions which can be used as standards for assessing future timber sales. The results of previous ratings will give the channel history of response to past timber harvesting. The Water Yield Analysis of

a recent timber sale on the Kootenai National Forest showed that the watershed had sustained a maximum probable increase in flow of 17% from an earlier timber sale, with little evidence of channel damage having taken place. This information was used to justify a maximum probable increase above 8% for the proposed timber sale. If such an analysis is not available for a watershed, then Channel Stability Ratings of nearby watersheds with similar elevation distribution, drainage density, channel gradient, meander frequency, and parent materials can be used for guidance.

Until the District accumulates enough data to establish a comparison of Channel Stability Rating to the maximum probable increase in annual flow, the following is given as an interim guideline, based upon field observations by the author.

| Channel Stability Rating | Maximum Probable Increase in Annual Flow |
|---|---|
| 38 - 50 | 16% - 14 |
| 51 - 76 | 14% - 12 |
| 77 - 114 | 12% - 8 |
| 115 + | 8% or less |

When applying the Channel Stability Rating, the entire length of the channel should be used to arrive at a weighted rating. A weighted rating is determined from each individual reach of the channel which is essentially the same throughout. The following example shows how a weighted rating is calculated. The rating for a reach is multiplied times its length in miles. This product is added to those of other reaches and the total divided by the total length of all reaches.

| | Rating | Length | R x L |
|---|---|---|---|
| Reach A | 70 | 2 | 140 |
| Reach B | 90 | 4 | 360 |
| Reach C | 120 | 1 | 120 |
| | Totals | 7 | 620 |

Weighted Stream Rating = 620/7 = 89

The Channel Stability Rating can also be used for more detailed project planning. For example, in laying out the transportation system, choices between alternative stream crossings should be influenced by the Channel Stability of these locations. By the same token the amount and type of timber harvesting in a streamside strip should be guided by the Channel Stability conditions. In combination with fisheries habitat data the Channel Stability Rating becomes an important piece of information for any management activity affecting the stream environment.

## Conclusion

In conclusion, the Water Yield Analysis which produces the maximum probable increase in total annual flow and the probable impact on the peak flow can be combined with the Channel Stability Rating to give the land manager a means of evaluating the hydrologic impact of vegetation manipulation. For review purposes a timber sale proposal should include both a Water Yield Analysis and Channel Stability Rating. Taken from the Schrieber Creek hypothetical example, the following is shown as a guide for timber sale proposals:

### Hydrologic Analysis

The weighted Channel Stability Rating for the two miles of stream channel is 44.

#### Average Annual Runoff

30-35 inch PPT zone - 294 AF
25-30 inch PPT zone - 733
20-25 inch PPT zone - 23
Total 1050 AF

#### Increases to Average Annual Runoff

1. Past Timber Harvesting

| Unit | Habitat Type | Years | Recovery Percentage | Original Inc. | AF |
|---|---|---|---|---|---|
| 1 | GF/Clun | 20 | .33 | 36 | 12 |
| 2 | DF/Phma | 20 | .40 | 33 | 13 |
| | | | | Total: | 25 |

2. Timber Sale Proposal

| Unit | Land Type | S.R. 1/ | ECC% 2/ | Acres | ECC 2/ | AF/Ac. | AF |
|---|---|---|---|---|---|---|---|
| 3 | 103 | 90% | 100 | 13 | 13 | 1.15 | 15 |
| 4 | 352 | 50% | 40 | 18 | 7 | 1.30 | 9 |
| 5 | 352 | 50% | 40 | 21 | 8 | 1.30 | 10 |
| 6 | 352 | 100% | 100 | 23 | 23 | 1.30 | 30 |
| 6 | 355 | 100% | 100 | 10 | 10 | 0.90 | 9 |
| 7 | 352 | 25% | 0 | 29 | 0 | 0 | 0 |
| 8 | 352 | 25% | 0 | 42 | 0 | 0 | 0 |
| | | | | | | Total: | 73 |

1/ S.R. means stand reduction, Figure 4.

2/ ECC% means percent equivalent clearcut, Figure 4.

Partial Cut

| Area | S.R. | AF/Ac. 1/ | AF |
|---|---|---|---|
| 390 | 60% | 0.15 | 58 |

1/ From Figure 4.

| | |
|---|---|
| Past Clearcutting | 25 |
| Proposed Timber Sale | 73 |
| | 58 |
| Roads | 6 |
| Maximum Probable Increase | 162 AF |

4. Percent (%) Increase

$$(162/1050) \times (100) = 15.4\%$$

Impact Upon Peak Flow

Cutting unit number 8 and the lower portion of the commercial thinning unit are the only areas of the proposal that might not contribute to the peak discharge period of the watershed. In both instances the amount of tree cover removed is not great enough to increase the water yield from cutting unit 8 nor accelerate the melt rate from the commercial thinning. Therefore, the entire maximum probable increase from this proposal is estimated to take place during the peak discharge period of the watershed. Since the channel is very stable, according to the field rating, it is believed the increase in flow will not cause channel damage nor increase the sediment load significantly.

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# APPENDIX

## FOREST HABITAT TYPES

| Abbreviation | | Scientific Name |
|---|---|---|
| WRC/Clun | - | Thuja plicata/Clintonia uniflora |
| WH/Clun | - | Tsuga heterophylla/Clintonia uniflora |
| WH/Oplo | - | Tsuga heterophylla/Oplopanax horridum |
| AF/Oplo | - | Abies lasiocarpa/Oplopanax horridum |
| AF/Clun | - | Abies lasiocarpa/Clintonia uniflora |
| GF/Clun | - | Abies grandis/Clintonia uniflora |
| S/Libo | - | Picea engelmanni/Linnaea borealis |
| DF/Libo | - | Pseudotsuga menziesii/Linnaea borealis |
| DF/Phma | - | Pseudotsuga menziesii/Physocarpos malvaceus |
| GF/Xete | - | Abies grandis/Xerophyllum tenax |
| DF/Syal | - | Pseudotsuga menziesii/Symphoricarpos albus |
| DF/Vaca | - | Pseudotsuga menziesii/Vaccinium caespitosum |
| DF/Xete | - | Pseudotsuga menziesii/Xerophyllum tenax |
| DF/Aruv | - | Pseudotsuga menziesii/Arctostaphylos uva-ursi |
| DF/Caru | - | Pseudotsuga menziesii/Calamagrostis rubescens |
| AF/Vasc | - | Abies lasiocarpa/Vaccinium scoparium |
| AF/Xete | - | Abies lasiocarpa/Xerophyllum tenax |
| AF/Mefe | - | Abies lasiocarpa/Menziesia ferruginea |
| MH/Mefe | - | Tsuga mertensiana/Menziesia ferruginea |
| AF/Lugl | - | Abies lasiocarpa/Luzula glabrata |
| MH/Xete | - | Tsuga mertensiana/Xerophyllum tenax |
| WBP/AF | - | Pinus albicaulis/Abies lasiocarpa |
| AL/AF | - | Larix lyallii/Abies lasiocarpa |
| DF/Agsp | - | Pseudotsuga/Agropyron spicatum |
| PP/Putr | - | Pinus ponderosa/Purshia tridentata |
| PP/Agsp | - | Pinus ponderosa/Agropyron spicatum |

## STREAM ORDER

The term stream order originated in the language of physical geography to describe the branching pattern of river systems. The smallest unbranched tributary is assigned the number one, or called first order. For our purposes, perennial streams shown on the 4 inch to the mile contour maps in use on the Kootenai National Forest will be the smallest first order streams. When two first order streams join, the stream from that point downstream becomes a second order stream. Likewise, the junction or confluence of two second order streams marks the beginning of third order streams and so on to higher orders. The water yield analysis is designed for third or fourth order streams, and the smallest third order stream will be at least one square mile in size and generally larger. The Schrieber Creek watershed is shown as an example of stream ordering. A third order stream can have lower order streams joining it without changing its ranking, as is seen on the diagram of stream ordering for Schrieber Creek.

# SCHRIEBER CREEK WATERSHED
# STREAM ORDER